Evaluation of the ear-tag sensor system SMARTBOW for detecting estrus events in indoor housed dairy cows

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Abstract. *Livestock farming technologies have a tremendous potential to improve and support farmers in herd management decisions, in particular in reproductive management. Nowadays, estrus detection in cows is challenging and many detection tools are available. The company Smartbow (Weibern, Austria) developed a novel ear-tag sensor, which consists of a 3D-accelerometer that records head and ear movements of cows as basis for algorithm development and further analyses. Estrus detection by the SMARTBOW system is primarily based on an increased activity combined with behavioral changes. In this study, the system was installed on a commercial dairy farm in Slovakia and Holstein-Friesian cows were equipped with SMARTBOW Eartag sensors. Exceeding cow specific thresholds for activity and behavioral changes, an estrus alert was generated. Retrospectively, reproductive performance data were used to evaluate the accuracy of estrus alerts generated by the SMARTBOW system. Sensitivity, specificity, positive and negative predictive value, accuracy, and error rate for detecting estruses were 97%, 96%, 98%, 94%, 96%, and 2%, respectively. In summary, the SMARTBOW system is suitable for an automatic estrus detection of estrus events in indoor housed dairy cows.*

Keywords. *Dairy cow, reproduction, estrus detection, sensor technology, accelerometer.*

Introduction

Good reproductive performance, is particularly based on a reliable estrus detection and determination of the optimum insemination time, and is important for successful dairy farming (Denis-Robichaud et al. 2018). Nowadays, estrus detection is often challenging for farmers because of a decreased duration of the visual signs of estrus, a less intensive expression of estrus behavior and a high proportion of estrus events occurring during night hours (Dobson et al. 2008; Crowe et al. 2018).

Additionally, visual estrus detection is labor and costs intensive. To achieve satisfactory detection rates it is necessary to observe animals several times per day (Saint-Dizier and Chastant-Maillard 2018). This is quite time-consuming and requires knowledge and skills of farmers and/or employees about behavioral signs of cows in estrus, which are often not self-evident for paid farm workers (Barkema et al. 2015). Hence, various technical devices were developed to assist the farmers and their employees in estrus detection.

The company Smartbow (Weibern, Austria) developed an activity monitoring system for wireless, continuous and real-time monitoring of physiological and pathophysiological conditions in cows. The ear-tag sensor SMARTBOW consists of an accelerometer for detecting head and ear movements in three dimensions (x-, y- and z-axis). By processing the data, information of animals' activity, rumination and localization inside the barn is provided. Estrus detection by the SMARTBOW system is primarily based on an increased activity and behavioral changes around estrus.

The aim of this study was to assess the suitability of the SMARTBOW system to detect cows in estrus. For this, reproductive performance data were retrospectively compared with estrus alerts generated by the SMARTBOW system.

Materials and Methods

All study procedures were approved by the institutional ethics committee of the University of Veterinary Medicine Vienna, Austria, in accordance with the national authority according to § 26 of the Law for Animal Experiments, Tierversuchsgesetz 2012 - TVG 2012 (BMWFW-68.205/0004-WF/V/3b/2016), as well as the Slovakian Regional Veterinary Food Administration.

Herd Description

The study was conducted between March 2016 and December 2017 on a commercial Slovakian dairy farm, housing approximately 2,700 Holstein-Friesian cows. Cows were kept in freestall barns with pens for approximately 250 animals, each equipped with full concrete floors and high bed cubicles. Cows received a Total Mixed Ration (TMR) and were milked in a rotary parlor twice a day. All animal related events (e.g., estrus, artificial insemination (**AI**), clinical diseases, treatments) were entered into the herd management software DairyComp 305 (**DC305**, Valley Agricultural Software, Tulare, USA) by responsible farm personnel. Heifers were kept on another farm site, thus, only multiparous cows were included in this study.

Reproductive Management

In all cows, reproductive tract was examined by palpation of the uterus and the ovaries per rectum between d 28 and 35 postpartum to detect uterine and ovarian disorders. Based on standard operating procedures (**SOP**), animals were treated according to health disorders (e.g., endometritis, cystic ovaries) and other management routines (e.g., induction and synchronization of ovulation) by using hormones (i.e., $PGF_{2\alpha}$, GnRH).

The voluntary waiting period was set at 50 days in milk (DIM). Cows detected in estrus were inseminated by two AI technicians based on the a.m.-p.m. rule. Cows not detected in estrus and bred by 64 DIM were subjected to a standard Ovsynch protocol (Pursley et al. 1995). Pregnancy diagnosis was performed between d 39 and 45 after AI by the herd veterinarian by ultrasound and confirmed approximately 90 d after AI by transrectal palpation of the uterus and its contents by an AI technician.

SMARTBOW System

Study animals were equipped with a SMARTBOW Eartag sensor (size and weight of 52 x 36 x 17 mm and 34 g) which was placed in the middle of the right ear. Acceleration data of head and/or ear movements of the animals (measuring range -2 g to +2 g) were recorded with a frequency of 1 Hz by the sensor. Afterwards, data were sent to receivers (SMARTBOW Indoor Receiver) installed in a distance of 20 m each, throughout the study pens. Those were connected with a local server (SMARTBOW Farm Server), on which data were processed by using specific machine learning algorithms. When activity and behavior changes exceeded a defined threshold, an estrus alert was generated.

For study purposes, only two pens of the farm were equipped with SMARTBOW Indoor Receivers and cows were kept due to management procedures approximately until 100 DIM in this study pens. Hence, sensor data were only available, if animals were allocated for this period of time to these study pens.

Study Design and Definition of Terms

Inseminations resulting from an Ovsynch protocol were excluded from statistical analyses, because we assumed that movement patterns of cows with induced estrus differ from cows showing natural signs of estrus. The comparison between induced estrus and natural estrus was not the objective of this study.

An estrus followed by AI which resulted in pregnancy was defined as ‘golden standard’ (**GS**). Furthermore, estrus events with an estrus interval of 18 to 25 d were defined as ‘true estrus’ (**TE**) events. This definition takes findings of Remnant et al. (2015) into account, that the physiological estrus interval is increasing upwards with parity and high milk yield. The estrus interval, therefore, was set for 18 to 25 d to enclose more study animals, but still remaining near the physiological estrus range. TE events included estrus events followed by AI, independent on resulting in pregnancy or non-pregnancy, as well as not followed by AI (Figure 1).

For the evaluation of the SMARTBOW system, (1) GS events and (2) TE events were classified, retrospectively, based on reproductive performance data (i.e., estrus, insemination) entered into DC305 matched with estrus alerts by the SMARTBOW system. If an estrus alert was associated with a GS or TE event, the alert was classified as ‘true positive’ (**TP**). In the case that no estrus alert was generated during a GS or TE event, it was classified as ‘false negative’ (**FN**). An estrus interval was classified as ‘true negative’ (**TN**), when no estrus alert occurred, and as ‘false positive' (**FP**), when an estrus alert occurred during an estrus interval (Figure 1).

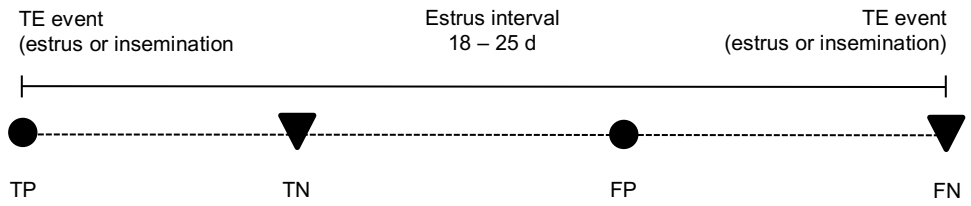

Figure 1. Scheme for assigning generated estrus alerts ● or not generated alerts ▼ of the SMARTBOW system. A ‘true estrus’ (TE) event was detected (‘true positive’, TP) or not detected (‘false negative’, FN), or no alert (‘true negative’, TN) or an alert (‘false positive’, FP) occurred between TE events with an estrus interval of 18 to 25 d.

Statistical Analyses

All reproductive performance data based on DC305 entries and estrus alerts by SMARTBOW were transferred to Microsoft Excel spreadsheets (MS Excel, version 14.0.7194.5000, Microsoft Corporation, Redmond, USA). To evaluate the performance of the SMARTBOW system for estrus detection, sensitivity, specificity, positive predictive value (**PPV**), negative predictive value (**NPV**), accuracy, and error rate (**ER**) were calculated with MS Excel. Further details are presented in Table 1.

Table 1. Parameters used for evaluating the performance of SMARTBOW for estrus detection.

Parameter	Calculation[1]	Definition
Sensitivity	TP / (TP + FN) x 100	Proportion of identified GS[5] / TE[6] events among all GS / TE events
Specificity	TN / (TN + FP) x 100	Proportion of non-alerted estrus intervals among all estrus intervals
PPV[2]	TP / (TP + FP) x 100	Proportion of detected TE events among all generated alerts
NPV[3]	TN / (TN + FN) x 100	Proportion of non-alerted non-estrus events among all non-alerted events
Accuracy	TP + TN / (TP + TN + FP + FN) x 100	Proportion of identified events among all events
ER[4]	FP / (FP + TP) x 100	Proportion of false estrus alerts among all generated alerts

[1]TP = true positive; FN = false negative; TN = true negative; FP = false positive.
[2]PPV = positive predictive value.
[3]NPV = negative predictive value.
[4]ER = error rate.
[5]GS = golden standard.
[6]TE = true estrus.

Results

For the evaluation of the estrus detection performance of SMARTBOW, 316 GS events of 316 cows and 263 TE events of 142 estrus intervals of 116 cows were used. The number of GS and TE events, correctly or incorrectly detected, and further test characteristics of the SMARTBOW system are presented in Table 2. On average, the duration of an estrus alert of correctly identified GS events was 16.9 ± 4.9 h.

Table 2. Performance of SMARTBOW for estrus detection in indoor housed dairy cows.

					Statistics %					
Events	SB[1] results	True (+)	False (-)	Cows	Sensitivity	Specificity	PPV[2]	NPV[3]	Accuracy	ER[4]
GS[5]	Positive (+)	306[a]		316	96.8					
	Negative (-)	10[a]								
TE[6]	Positive (+)	254	6	116	96.6	95.8	97.7	93.8	96.3	2.3
	Negative (-)	9	136							

[1]SB = SMARTBOW system.
[2]PPV = positive predictive value.
[3]NPV = negative predictive value.
[4]ER = error rate.
[5]GS = golden standard events used for calculation based on confirmed pregnancy.
[6]TE = true estrus events used for calculation.
[a]Results confirmed by pregnancy.

Sensitivity was calculated separately for GS events which were confirmed by pregnancy and for TE events. Comparing both results, sensitivity was similar among GS and TE events. For calculation of specificity, 142 estrus intervals were classified into TN, if no alert occurred, or FP, if an alert occurred. Hence, during 136 estrus intervals no alert (TN) and during 6 estrus intervals an alert (FP) was generated.

Discussion

The vast field of dairy technologies has a tremendous potential to improve health, welfare and, reproduction in dairy cattle (Barkema et al. 2015). Today´s reduced intensity of estrus expression and short estrus duration (Dobson et al. 2008) were main reasons for developing automatic estrus detection systems in cows.

The aim of this study was to evaluate the suitability of a novel system for estrus detection in indoor housed dairy cows. A wide range of factors which have an impact on the performance of activity monitoring systems for estrus detection have been recorded. The review of Saint-Dizier and Chastant-Maillard (2018) classified these factors and pointed out that lowering the threshold of activity may increase estrus detection with the consequence of lower specificity and PPV due to an increase in FP alerts. FP alerts are caused by 'general overactive' cows or by management procedures (e.g., hoof trimming, regrouping). Overall, checking a cow more often can be considered as more effective, because missing one TE event or more causes an increase of the calving interval and subsequently, greater economic losses for the farm (Inchaisri et al. 2010).

Furthermore, taking days of inseminations to define a true estrus event will underestimate silent ovulations. As a result, less FN emitted alerts will lead to a greater sensitivity, whereas blood or milk progesterone measurements give a reliable indication of estrus status and should be used as golden standard for estrus detection sensors (Rutten et al. 2013; Saint-Dizier and Chastant-Maillard 2018). Consequently, results of the TE events of this study should be interpreted with caution, keeping in mind that measuring progesterone was not feasible to be used as golden standard in this part of the study. In contrast, GS events indicate to be correct, because cows got successfully pregnant after insemination.

Sensitivity of GS events and PPV of TE events for the SMARTBOW system in this study were calculated as 97% and 98%, respectively. Other studies that evaluated automatic estrus detection devices by using progesterone measurements as golden standard found sensitivity and PPV ranging from 76 to 91% and 40 to 92% for neck collar activity-meter, from 63 to 71% and 71 to 74% for pedometer, and from 56 to 84% and 83 to 94% for collar-mounted accelerometer (Roelofs and van Erp-van der Kooij 2015; Roelofs et al. 2017; Saint-Dizier and Chastant-Maillard 2018). Comparing these results, it can be concluded, that the SMARTBOW system is suitable for estrus detection in indoor housed dairy cows.

Additionally, numerous biological factors are described to contribute to a decrease in expression of estrus signs and, hence, the performance of automatic estrus detection systems. Reith and Hoy (2018) reported cows being 2.3 to 6 times more active at the time of estrus compared to inter-estrus, but, for instance, first postpartum ovulation, high milk yield, BCS, parity, uterine health, and lameness have a negative effect on activity (Roelofs and van Erp-van der Kooij 2015; Saint-Dizier and Chastant-Maillard 2018). Hence, additional alterations in behavior patterns during estrus have to be found and measured. Several studies documented that rumination and feeding time are decreased one day before and at estrus (Reith and Hoy 2012; Pahl et al. 2015). Consequently, for the future, sensor technologies for automatic estrus detection will have to focus not only on an activity increase, but also in behavior pattern changes around estrus, as already considered by the SMARTBOW system.

Conclusion

By recording an increase of activity as well as of other changes in animal behavior, the sensitivity and PPV of the SMARTBOW system in detecting estrus events was 97% and 98%, respectively. Hence, the system is considered as suitable for an automatic detection of estrus events in indoor housed dairy cows.

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